UNCLASSIFIED

AD NUMBER	
AD021402	
CLASSIFICATION CHANGES	
TO:	unclassified
FROM:	confidential
LIMITATION CHANGES	
TO: Approved for public release; distribution is unlimited.	
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; OCT 1953. Other requests shall be referred to Office of Naval research, Arlington, VA 22203.	
AUTHORITY	
31 Oct 1965, DoDD 5200.10; ONR ltr, 27 Oct 1977	

THIS PAGE IS UNCLASSIFIED

AD NUMBER
AD021402
CLASSIFICATION CHANGES
TO: **confidential**
FROM: **secret**
AUTHORITY
31 Oct 1956, DoDD 5200.10

SECRET
SECURITY INFORMATION

042

AD No.
ASTIA FILE COPY

PROJECT MICHAEL

CONTRACT N6-ONR-27135

COLUMBIA UNIVERSITY

HUDSON LABORATORIES

DOBBS FERRY, N.Y.

This document has been declassified in accordance with OPNAV INST 5510.17, paragraph ... the security classification assigned hereto is ...

By direction of
Chief of Naval Research (Code ...)

RESEARCH SPONSORED BY

OFFICE OF NAVAL RESEARCH

BEST AVAILABLE COPY

0515

SECRET
SECURITY INFORMATION
53AA-18551

SECRET
SECURITY INFORMATION

CU-17-53-ONR-271-Phys

COLUMBIA UNIVERSITY

Hudson Laboratories

Dobbs Ferry, N. Y.

PROJECT MICHAEL

Contract N6-ONR-27135

Technical Report No. 12
A Preliminary Report on Sound Transmission at San Juan Puerto Rico

by

R. A. Frosch, A. N. Guthrie
H. H. Loar, H. L. Poss

W. A. Nierenberg
Director

Research Sponsored by
Office of Naval Research

Further distribution of this report, or of an abstract or reproductions, may be made only with the approval of Chief of Naval Research (Code 466).

SECRET

SECURITY INFORMATION

October 1, 1953

Copy No. 042

This report consists of 39 pages

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

SECRET
SECURITY INFORMATION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Part I

Part II

Part III

A PRELIMINARY REPORT ON SOUND TRANSMISSION AT SAN JUAN, PUERTO RICO

by

R. A. Frosch, A. N. Guthrie, H. H. Loar, H. L. Poss

INTRODUCTION

In order to choose and operate effective listening stations to be used in the passive detection of ships and submarines, it is necessary to understand the transmission of sound in the ocean. It is particularly important to understand the effect of the characteristics and configuration of the ocean bottom on this transmission. To further this understanding a continuing investigation of sound recorded on the hydrophones of the Hudson Laboratories Puerto Rico Field Station has been undertaken. In this report, the results of a preliminary analysis of data obtained using explosive and 30 cps continuous sources are presented. The experimental results are compared with predictions derived from ray computations for this region.

CONCLUSIONS

1. Propagation beyond the end of the 3° slope at Puerto Rico is characterized by deep water focussed transmission with 35 mile peaking.

2. From the deep hydrophone out to the end of the 3° slope (a distance of 20 - 25 miles) the sound intensity suffers inverse square spreading due to the geometry of the slope and an additional loss of several db due to imperfect bottom reflections.

3. For the shot data, the intensity change down the initial slope can be matched fairly well within the function $AR^{-2.26}$. A bottom velocity of 6625 ft/sec and a density of 2 give a bottom reflectivity yielding this intensity-range law. This velocity is in excellent agreement with that calculated from seismic refraction shots near the deep hydrophone. This agreement indicates that the technique of comparing ray tracing intensities derived from particular assumptions about the bottom with data from shot runs may be used to provide information as to the reflection characteristics of the bottom.

4. The initial fall-off of 30 cps sound intensity with range follows the law AR^{-3}. Farther out, the sparse 30 cps data are in agreement with the shot data.

5. The intensities from shot data for the shallow hydrophone are 3 db below those for the deep hydrophone. This is presumably due to further attenuation of the sound through multiple reflections on the slope.

6. The comparison of the Puerto Rico intensities with intensities taken at Eleuthera indicates that the latter are 3-4 db above those measured at the Puerto Rico 35 mile peaks.

PART I

TRANSMISSION USING SHOT SOURCES

by

A. N. Guthrie and H. H. Loar

Sound transmission experiments using explosive charges as sources were conducted at the Hudson Laboratories Puerto Rico Station during March and April of 1953. The results presented are those of a preliminary analysis of two exercises:

1. Operation 13 -- Event DOG

   The USS ALLEGHENY traveled at a speed of 10 knots on course 000° from San Juan, dropping 2 lb TNT charges at 12 minute intervals.

2. Operation 14 (AMOS Cruise 12, Special Event DOG)

   The USS SAN PABLO traveled at a speed of 10 knots on course 007° from San Juan, dropping 2 1/4 lb C-3 composition demolition blocks at 6 minute intervals.

In both exercises, recordings were made from the shallow (approximately 200 fathoms) and deep (approximately 465 fathoms) hydrophones. Moving coil hydrophones were used for Operation 13 and barium titanate hydrophones were used for Operation 14.

A block diagram of the recording equipment is shown in Fig. 1. Amplified signals from both the deep and the shallow

hydrophone cables were recorded on dual channel frequency modulated Ampex recorders during Operation 14 and on dual channel Magnecorders during Operation 13. In order to measure sound travel times, the signal from the deep hydrophone was recorded on a Brush oscillograph along with a break second chronometer signal and the radioed shot signal from the shooting ship. The distance of the shot from the hydrophone was determined by multiplying the travel time of the first sound arrival by the average sound velocity in the surface sound channel.

The range was sufficiently great so that it is reasonable to assume that the energy reaching the hydrophone from the source was propagated in plane waves. In this case, the rate at which energy crosses a unit area normal to the propagation direction is equal to

$$E' = \frac{p^2}{\rho c}$$

where

ρ is the water density
c is the sound velocity
p is the instantaneous excess pressure due to the sound source

The total energy from a shot crossing unit area (of the listening hydrophone) is then

$$E = \frac{1}{\rho c} \int_0^T p^2 dt$$

where the integral is taken from the time of the initial sound arrival ($t=0$) until after the last sound from the shot has reached the hydrophone ($t=T$).

Analog computer units made by George A. Philbrick Researches, Inc., were used to evaluate $\int_0^T p^2 dt$. The hydrophone signals recorded on the magnetic tapes are directly proportional to the pressure excesses at the hydrophone. These signals, reproduced by playback of the recordings, are filtered, amplified, squared, and then integrated over the time of arrival of shot energy using the analysis instrumentation shown in Fig. 1. The squaring circuit was frequently checked to insure that the output voltage was proportional to the square of the input voltage. In spite of careful adjustments, the points on a plot of output vs $(\text{input})^2$ would scatter from a straight line by as much as 5%. Therefore, the amplifier gains were adjusted for each shot to keep approximately the same voltage amplitude into the squaring circuit.

If $\int_0^T p^2 dt$ were divided by T, the result would be the average p^2 at the hydrophone over the time interval during which the shot energy is arriving. A more useful quantity for transmission studies results if $\int_0^T p^2 dt$ is divided by one second. This gives the average p^2 at the hydrophone which would exist if all the energy arrived during one second. To convert this to a decibel scale, the results given in this report are measurements of

$$10 \log \int_0^T p^2 dt.$$

A typical Brush oscillogram obtained using the instrumentation of Fig. 1 is shown in Fig. 2. Channel 1 is a record of the input to the squaring circuit. Channel 2 is a record of the output of the integrating circuit: the total deflection of the galvanometer is proportional to $\int_0^T p^2 dt$. There is no contribution to this integral from noise recorded on the magnetic tapes or noise from the playback circuits since the noise is cancelled out in the adding circuit. The "adder" is designed to add or subtract an adjustable constant voltage to its input signal.

In running off one of the shots, the following procedure was followed:

1. With the recorder on "playback", the adder was adjusted to give no signal out of the integrator until the initial arrival from the shot.

2. If after the last shot sound arrival the voltage out of the integrator remained constant (i.e., if the deflection of the galvanometer pen of Channel 2 remained unchanged), the record was considered good.

3. If the Brush pen did not stay at a given deflection after the shot arrivals, it was an indication that the noise level had not been properly subtracted and the record was discarded. A new oscillogram of the shot was then made.

From Fig. 2, it is evident that it is possible to measure the energy arriving by each ray path. However, only the total shot energy as a function of range is discussed in this report.

The pressure level measured at the deep hydrophone is about 3 db above the level at the shallow hydrophone (Fig. 3). That is,

in terms of defensive monitoring, the deep hydrophone will monitor an area four times as large as that covered by the shallow hydrophone, assuming cylindrical spreading.

In Fig. 4 the results of Fig. 3 have been replotted after adding a term (10 log R) to correct for cylindrical spreading. For ranges greater than 30 miles, the pressure levels at the peaks seem to be consistent with cylindrical spreading. However, for ranges less than 30 miles, the pressure level falls off more rapidly than expected for spherical spreading.

Figs. 5 and 6 show a comparison of the pressure levels at the Puerto Rico deep hydrophone with the pressure levels measured on the "good" azimuth[1] at Eleuthera. Data for some ranges are missing from these curves because not all the shots have yet been analyzed in the 20-40 cps region. At Eleuthera the levels fall off almost cylindrically and are from 3 to 4 db above the peak levels at Puerto Rico. The difference can undoubtedly be attributed to loss on the slope from the hydrophone out to about 25 miles at Puerto Rico.

A more detailed analysis of these results will be prepared in the near future.

PART II

TRANSMISSION USING 30 CPS CONTINUOUS SOURCE

by

H. L. Poss

During February, 1953, using as a detector the deep (465 fathoms) moving coil hydrophone of our Puerto Rico Station, the pressure levels from a 30 cps source were measured out to source distances of 300 miles due north of the hydrophone. The source was an A Mark 6(b) minesweeping gear, modified to operate at 30 cps with a high degree of frequency stability. This source was described previously in a separate report.[2]

The first 27 miles of range were covered almost continuously in a series of runs in which the source was towed by the USS ALLEGHENY. The source depth was 42 feet. The towing speed was limited to about 3 knots so that it was not practical to cover the full range by this procedure. Instead, the source was operated at various stations along the range while the ALLEGHENY was drifting. It would then be lifted clear of the water so that normal cruising speed could be maintained to the next station. At each drift station, the source was operated at depths of 42 feet and 84 feet. In this preliminary report, results are presented for the shallower depth at distances out to 157 miles for comparison with shot data.

The ship's position was determined by Loran and celestial navigation. As a check, it was possible to determine the ship's distance from the hydrophone in most instances by having the sound source turned off at a specified time, communicated to the shore-based laboratory by radio, and noting the interval which elapsed until the hydrophone signal disappeared. This interval could be determined to about a second. The distance calculated from these travel times agreed quite well with those obtained by the navigation methods.

To measure pressure level, the hydrophone signal was passed through a selective amplifier having a bandwidth of about 1 cps and was recorded on a logarithmic level recorder having a 50 db range. Beyond 30 miles, the signal to noise ratio was usually too low for reliable measurements to be taken in this way and recourse was made to a bank of very selective tuning fork filters having Q's of about 8000. The bandwidth of such a filter at the half power points is 0.004 cps. The filters have been described in other reports.[3,4] Individual filters were tuned to frequencies at intervals of 0.01 cps above and below 30 cps and their outputs were recorded on linear level recorders. They were selective enough to detect the Doppler shift in frequency of the source resulting from the ship's rate of drift.

In order to measure pressure level, it was necessary to multiply the filter output by a factor to take into account the attenuation caused by the signal frequency differing slightly from the resonant frequency of the filter. The signal frequency was

determined with respect to a 30 cps tuning fork oscillator used as a reference standard by a phase comparison method described in another report.[4] Knowing the Q's of the filters and their resonant frequencies with respect to the standard, the correction could then be made. In measuring levels, use was made only of the filters having the highest outputs, that is, those closest to the signal frequency. The calibration of the hydrophone was known so that it was possible to obtain absolute pressure levels.

The signal level would frequently have large fluctuations at any particular station. These fluctuations are probably attributable to multi-path interference effects. At each drift station, the average level over the time of observation is plotted.

Out to 27 miles, the region of almost continuous coverage, the square of the pressure falls off at a rate approximately proportional to R^{-3} (Fig. 7). The next point at 38 miles is one of very low level in agreement with the shot data and ray analysis. The remaining points are too widely separated to permit the shape of the curve to be inferred, but their values appear to be consistent with the peaks and dips appearing in the more detailed shot data available in this region (Fig. 8).

It is planned to give a more detailed analysis and description of these and other results obtained with the 30 cps source in a later report.

PART III

RAY THEORY OF TRANSMISSION

by

R. A. Frosch

Detailed ray tracings have been made for the Puerto Rico deep hydrophone, and intensity range curves based upon ray densities have been made from these.

Bottom Contour

The bottom contour was taken from a fathogram made by the USS ALLEGHENY during an actual run along 000°T from the deep hydrophone. Bathymetric work done since indicates that navigational errors were made during this run, so that the bottom used is somewhat inaccurate. The possible effects of changing the bottom to correct configuration will be mentioned later in this report.

The hydrophone was taken to be at 2790 ft. From the hydrophone out about 20 miles, the bottom slopes off at about 3° until a depth of 8400 feet is reached (Fig. 9). From this point out to about 40 miles the slope is about 7° down to the Puerto Rico trench. The trench is between 23,000 and 25,000 feet deep. The shallowest point on the far side of the trench is at about 130 miles from the hydrophone and is 16,800 feet deep.

Velocity Profile

The velocity profile used in these ray tracings was constructed from a considerable quantity of data. A large number of velocity profiles for the area, for which we are indebted to the Woods Hole Oceanographic Institution, were plotted on one graph, together with profiles computed from Hydrographic Office data taken off San Juan, and from bathythermograph slides taken during the experiments discussed in this report. A curve, drawn by hand to best fit these data, was used in this computation (Fig. 10). The salient features for the month of March are a surface sound channel extending to 360 feet, and a main sound channel axis at 4100 feet.

Ray Structure

Rays were traced every 5° from 14° with the horizontal (shallowest angle ray reaching the surface) to 39°, and every 1° from 39° to 59°. Rays of shallower angle than 42° do not continue to go to the surface after several reflections from the 3° slope. No ray reflected from the 7° slope, after several bounces on the 3° slope, continues to go to the surface (see Table I). Hence, the transmission from large ranges is provided by three discrete cones of rays: 42°-44°, 48°-51°, 54°-57°. The bottom acts as a baffle preventing other rays from reaching large ranges.

All rays reaching large ranges have their last bounce on the 3° slope between 13 miles and the end of the slope (20 miles), and then behave at larger ranges as deep water transmitted rays (Fig.9).

TABLE I

V = 7000 ft/sec

$\rho = 2$

θ	Range of last surface hit in miles	Reflection correction after n hits on bottom-db 1	2	3	Total hits db	Depth, last hit on downslope, ft.	No. of hits on 3° downslope	No. of hits on 6° downslope
13.718	5					6645	1	
19	2					3913	1	
24	4					5051	2	
29	7					6235	3	
34	11					7496	4	
39	14					9925	5	
41	12					7818	5	
42	∞					7401	5	
43	∞					7056	5	
44	∞					6769	5	
45	16					12858	5	1
47	14					8415	5	1
48	∞	-.97			-.97	7964	6	
49	∞	-1.55			-1.55	7575	6	
50	∞	-1.94			-1.94	7255	6	
51	∞	-2.22			-2.22	6965	6	
52	17	-2.52			-2.52	11356	6	1
53	16	-2.70	-2.92		-2.92	9954	6	1
54	∞	-3.01	-4.19		-4.19	8599	7	
55	∞	-3.19	-4.82		-4.82	8028	7	
56	∞	-3.57	-5.38		-5.38	7664	7	
57	∞	-3.57	-5.85		-5.85	7370	7	
58	18	-3.77	-6.38		-6.38	13292	7	1
59	17	-3.98	-6.73	-7.45	-7.45	11136	7	1

A few are bottom reflected at the divide across the trench. It is this deep water transmission characteristic which is responsible for the 35 mile peaking seen in the experimental results. The major intensity loss takes place between the hydrophone and the end of the 3° slope. This loss is due partly to the spreading of the rays as they bounce down the slope and partly to loss on reflection.

Intensity Computation

The intensity from initial angle ϕ_0 is taken to be proportional to the cross sectional area of the small bundle of rays originating around ϕ_0. Following a suggestion made by members of WHOI [5,6] this is computed in the following manner:

If ϕ_0 is the initial angle of the ray and n the number of bounces (or refracted inversions) before reaching the surface at range R, one plots, separately for each value of n, log Sin ϕ vs R^2. If this curve is differentiated and multiplied by $\frac{\sin \phi_0}{\sin \phi_1}$, where ϕ_1 is the angle of the ray at range R, the resulting quantity is proportional to the intensity due to rays with n bounces.

The curves were differentiated using the Lagrange interpolation formula applied to successive groups of 3 points. This is equivalent to fitting each 3 points of a curve with a second order curve, and then taking the derivative of the curve at the middle point of the three to be the derivative of the graph at that point.

Each point was then corrected for reflection loss in bouncing off the bottom This correction was made assuming the Rayleigh

reflection law. Computations were made for several values of sound velocity and density of the bottom (Table II).

TABLE II

Velocity in Sediment	$\rho_{Sed} / \rho_{Water}$	ρc
5700	1.5	8550
6000	2	12000
7000	2	14000
rigid		

Discussion

One of the resulting intensity curves is shown in Fig. 11. The effect of the bounces may be seen from Table I. Of particular note in Fig. 11 is the peaking at about 55, 90, 125 and 155 miles, in good agreement with the experimental data, which peaked at 56, 95, 126 and 163 miles. The infinitely deep troughs between the peaks represent shadow zones. The oscillations at small ranges, (less than 25 miles) are due to the partial separation of the rays into arrival groups with range, i.e., the range intervals in which rays arrive at the surface having had 1,2,3, etc. bottom reflections only partly overlap. Each successive bottom reflection further attenuates the rays, so that the whole

group of twice reflected rays is several db below the once reflected rays, etc. (Table I). Furthermore, the steeper angled rays, which are most attenuated upon bottom reflection, arrive at the surface after n bottom reflections at shorter ranges than the shallower angled rays. There are some possible indications of this oscillatory behavior in the experimental data at 15 and 23 miles.

The lines marked "probable focussing" in Fig. 11 correspond to points of vertical slope on the log Sin ϕ_0 vs R^2 curves. Insufficient rays were traced to be certain that they really are points of vertical slope.

A plot of log p^2 vs log R for the experimental shot data can be fitted moderately well by a straight line of slope -2.26 ± 0.1 (fit by eye) Fig. 12. Similar plots (Fig. 13) for the ray tracing intensities between 5 and 25 miles give slopes as shown in Table III.

TABLE III

V Water = 5000 ρ Water = 1

Velocity	Density	Slope
5700	1.5	$-4.8 \pm .5$
6000	2	$-2.76 \pm .3$
7000	2	$-2.12 \pm .1$
rigid		$-2 \pm .1$
experimental shots		$-2.26 \pm .1$

The errors given correspond to the outside limits of the slopes of possible straight line fits. If we plot these slopes vs the corresponding ρ^{o} (Fig. 14), we see that the experimental result corresponds to about $\rho^{o} = 13{,}250 \pm 600$, which, if we take $\rho = 2$, gives

$$v = 6625 \pm 300 \text{ ft/sec } (\pm < 5\%).$$

Preliminary refraction shooting at Puerto Rico[2], taken together with the results of previous work by the staff of the Lamont Geological Observatory[7], suggests that the structure of the bottom near the deep hydrophone is as shown in Fig.15. If the top sediment layer continues to pinch off at 4° rate, it would be completely missing at less than 2 miles from the hydrophone. In this case, the bottom velocity on the slope would be 6650 ft/sec, in fortuitously good agreement with the result obtained by comparing the ray tracing results with the shot data.

A log p^2 vs log R plot for the 30 cps data (Fig. 7) gives a slope of -3 between 5 and 30 miles. This might be attributable to ray path interference, but it is difficult to see how this could affect the overall rate of fall-off with range. The expected effect would be interference oscillation with a period of the order of a wave length, 167 feet, or so. A dispersive bottom with a lower velocity for lower frequencies may be indicated here.

The appearance of the various intensity range diagrams is very similar to Fig. 11, which is for 7000 ft/sec in the bottom. Aside from the initial fall-off of intensity, the most predominant characteristic of the intensity range curves is the peaking. In Tables V and VI are tabulated the ranges and heights of these peaks, the latter neglecting focussing. Judging from the peak heights, a suitable bottom velocity would appear to be between 5700 and 6000 ft/sec, since such a velocity would minimize $(I_{10} - I_p)$ shot - $(I_{10} - I_p)$ rays. (I_{10} = intensity at 10 miles, I_p at a peak.) However, displacement in the ranges of the theoretical curve by 4 miles, as indicated by Table I, Col. 7, to produce better agreement of the peak position, makes the new relative peak amplitudes:

TABLE IV

$(I_{10} - I_p)$ rays - $(I_{14} - I_p)$ shots.

Peak No.	5700	6000	7000	Rigid
1	-10	-3	-1	1
2	-10	-3	-1	-2
3	- 0	0	1	1
4	-17	2	1	5

The difference is minimized, though not well, somewhere about 7000 ft/sec.

TABLE V

Range of Peak in Miles

Peak No.	5700	6000	7000	Rigid	Shot Data	Shot -7000	Shot)Considering focussings -7000)to define peaks
1	54	55	55	55	55	0	0
2	87	87	87	87	94	7	5
3	121	121	121	121	126	5	2
4	155	159	160	161	163	4	4
						4 ⟌16 = 4	4 ⟌110 = 2.8

Focussing at 89 and 124 miles

TABLE VI

(Intensity at 10 Miles)-(Intensity at Peaks)

Peak No.	5700	6000	7000	Rigid	Shot Data
1	19	12	10	8	14
2	19	14	12	13	16
3	18	12	11	11	17
4	26	18	15	11	21

Such a displacement might be indicated by the correct bottom, which has a knee some 15 miles farther out than the bottom used for the ray tracings. However, the above tests are hardly sensitive as the scatter of both shot data and computations is probably at least 2 db.

* * *

ACKNOWLEDGEMENTS

The authors wish to thank Miss Betsy Singer and Miss Sandra Taussig, who integrated the shot data, and (Mrs.) Barbara B. Brown, who traced the rays and computed the intensity curves.

The hydrographic data were kindly supplied by Woods Hole Oceanographic Institution and U.S. Navy Hydrographic Office.

Preliminary data on refraction shooting results at Puerto Rico were supplied by Dr. M. Vertner Brown.

REFERENCES

1.) Guthrie, A. N., and Loar, H. H. Transmission tests at USNEF, Eleuthera - Part II. Hudson Laboratories, Tech. Rpt. No.7. 1953.

2.) Beck, H., and Sonnemann, H. Conversion of the A Mark 6(b) minesweeping gear to a 30 cycle sound source. Hudson Laboratories, Tech. Rpt. No. 8. 1953.

3.) Project Michael progress report. Hudson Laboratories, July 1,1952.

4.) Project Michael progress report. September 16, 1952 - December 31, 1952. Hudson Laboratories. 1953.

5.) Sonar research April 1, 1951 - June 30, 1951. Woods Hole Oceanographic Institution, Ref. No. 51-61. July, 1951. p. 9.

6.) National Defense Research Committee. Summary Tech. Rpt. of division 6, Volume 8, Physics of sound in the sea. Part I, Transmission. 1946. p. 51.

7.) Ewing, M., and Worzel, J. L. Gravity anomalies and structure of the West Indies. Bulletin of the Geological Society of America. In press.

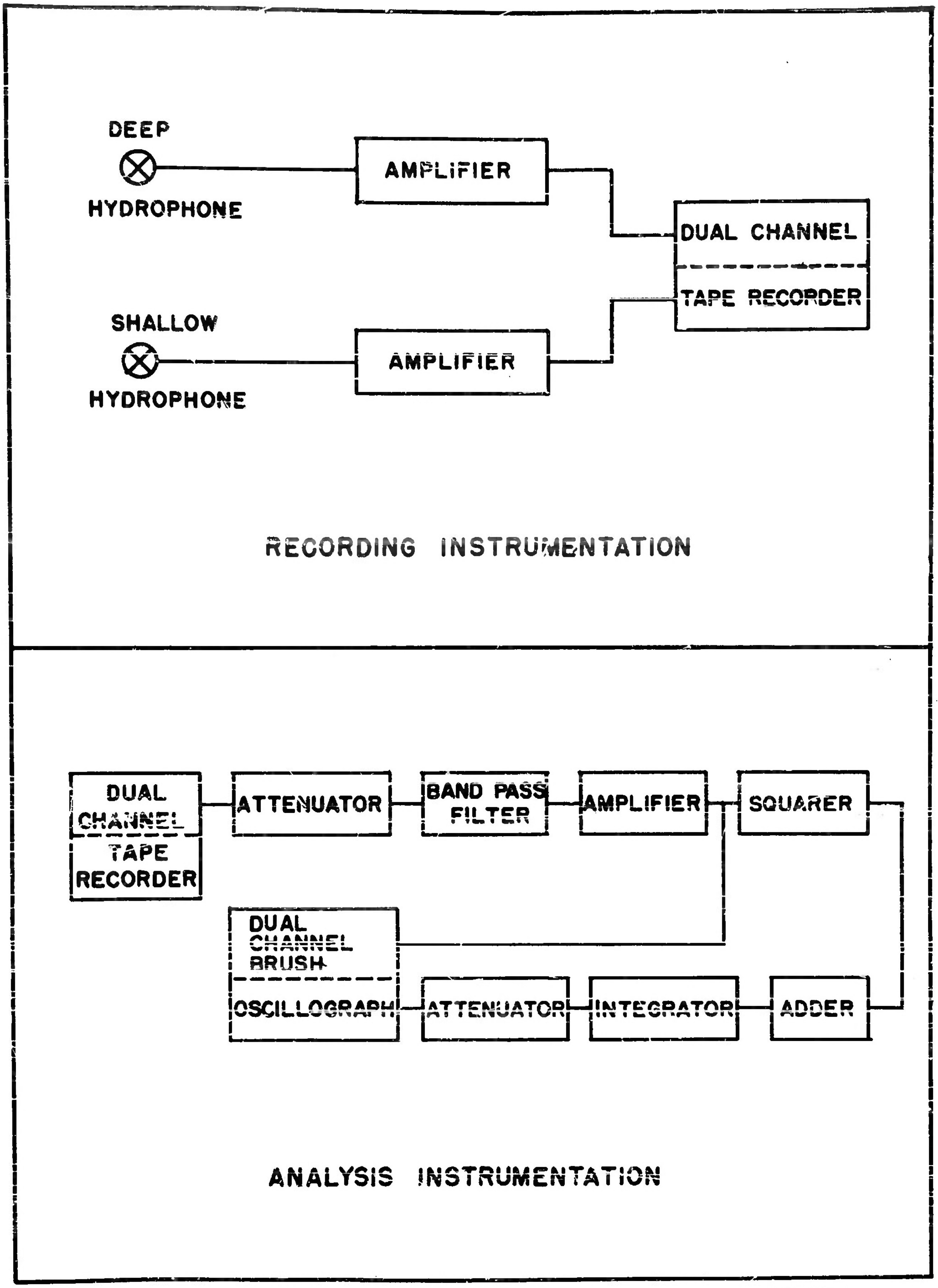

DEEP
HYDROPHONE
AMPLIFIER
DUAL CHANNEL
TAPE RECORDER
SHALLOW
HYDROPHONE
AMPLIFIER
RECORDING INSTRUMENTATION
DUAL CHANNEL
TAPE RECORDER
ATTENUATOR
BAND PASS FILTER
AMPLIFIER
SQUARER
DUAL CHANNEL BRUSH
OSCILLOGRAPH
ATTENUATOR
INTEGRATOR
ADDER
ANALYSIS INSTRUMENTATION

FIG. 1

OSCILLOGRAM OF SHOT OF PROBLEM TIME 0836

FREQUENCY 53-106 CPS-RANGE 87.8 MILES

CHANNEL 1 - INPUT SIGNAL TO SQUARER (RECTIFIED)

CHANNEL 2 - OUTPUT OF INTEGRATOR

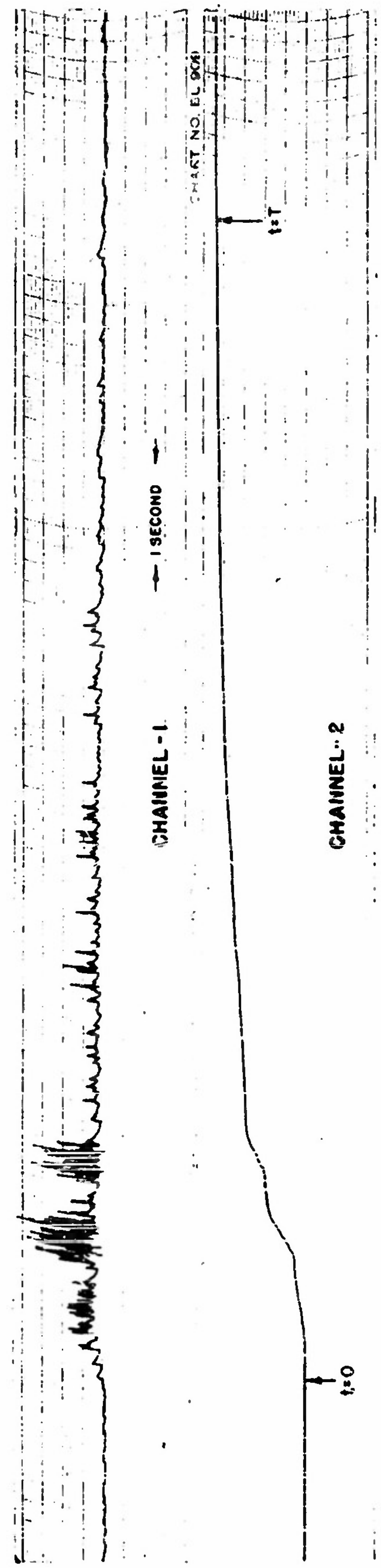


FIG. 2

SECRET

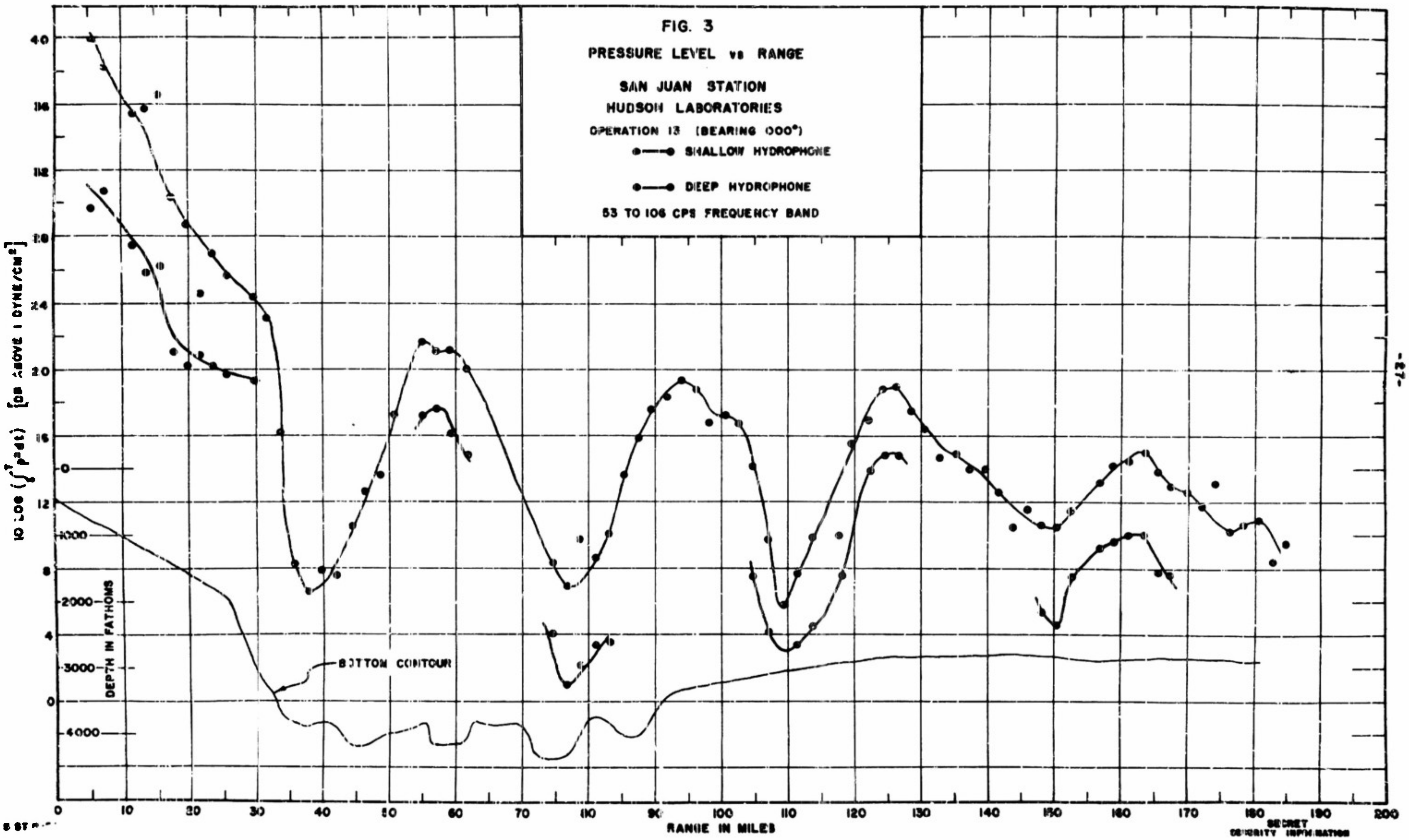


FIG. 3

PRESSURE LEVEL vs RANGE

SECRET
SECURITY INFORMATION

SECRET

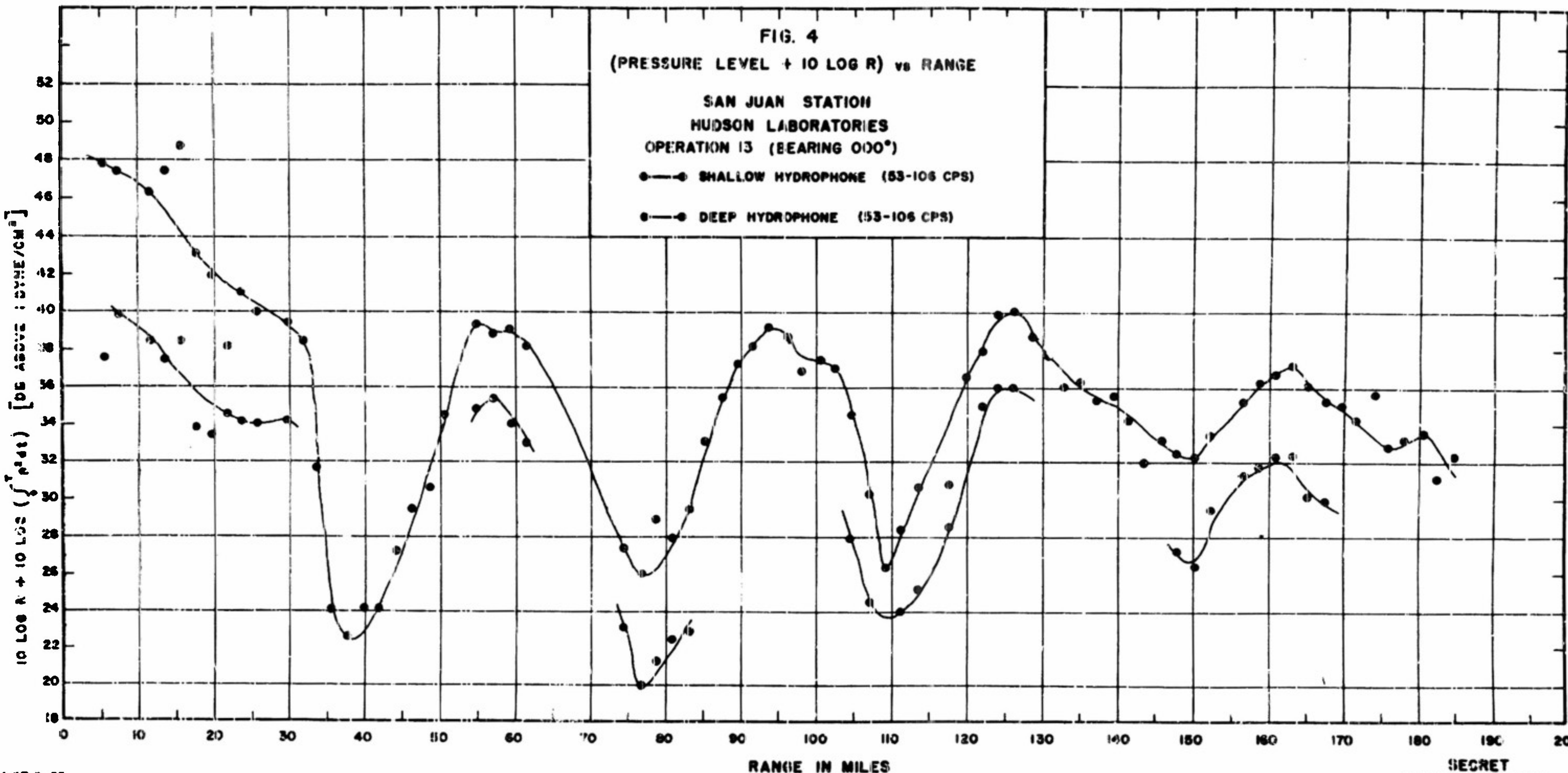


FIG. 4
(PRESSURE LEVEL + 10 LOG R) vs RANGE
SAN JUAN STATION
HUDSON LABORATORIES
OPERATION 13 (BEARING 000°)

4 ST 8-53

SECRET
SECURITY INFORMATION

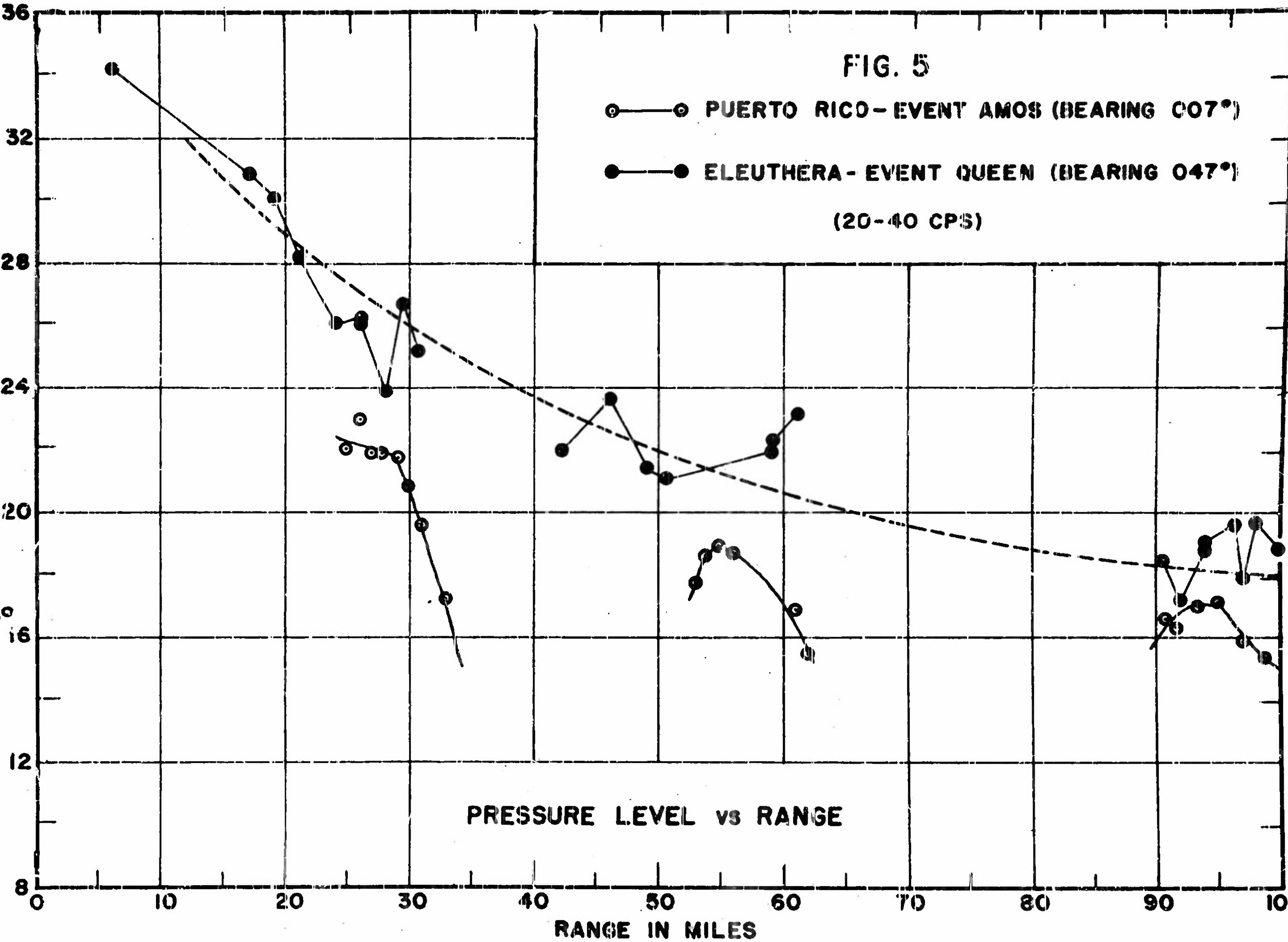


FIG. 5
PUERTO RICO - EVENT AMOS (BEARING 007°)
ELEUTHERA - EVENT QUEEN (BEARING 047°)
(20-40 CPS)
PRESSURE LEVEL vs RANGE
RANGE IN MILES
10 LOG $\left(\int_0^T p^2 dt\right)$ DB ABOVE 1 DYNE/CM²
36
32
28
24
20
16
12
8
0
10
20
30
40
50
60
70
80
90
100

FIG. 6

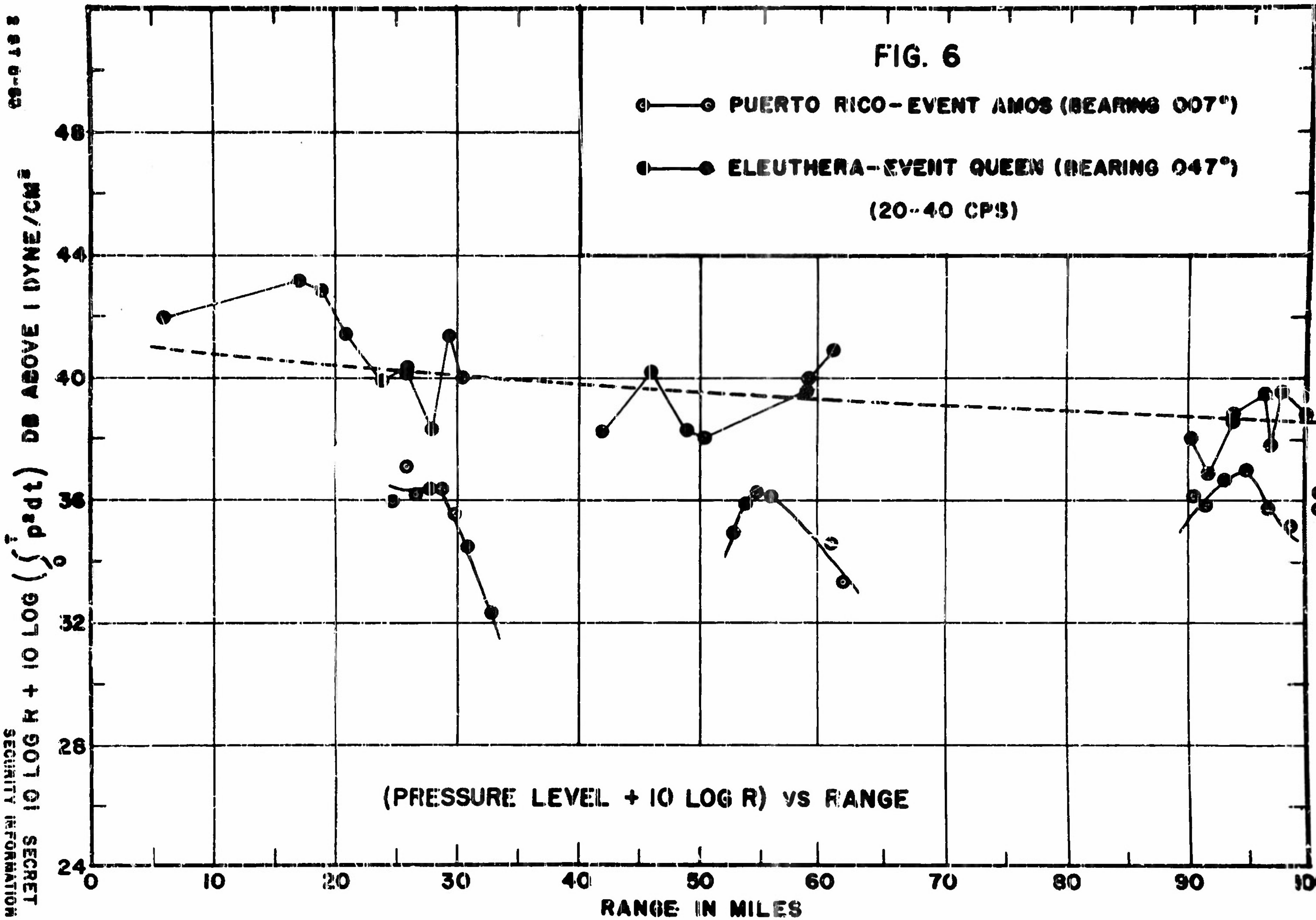
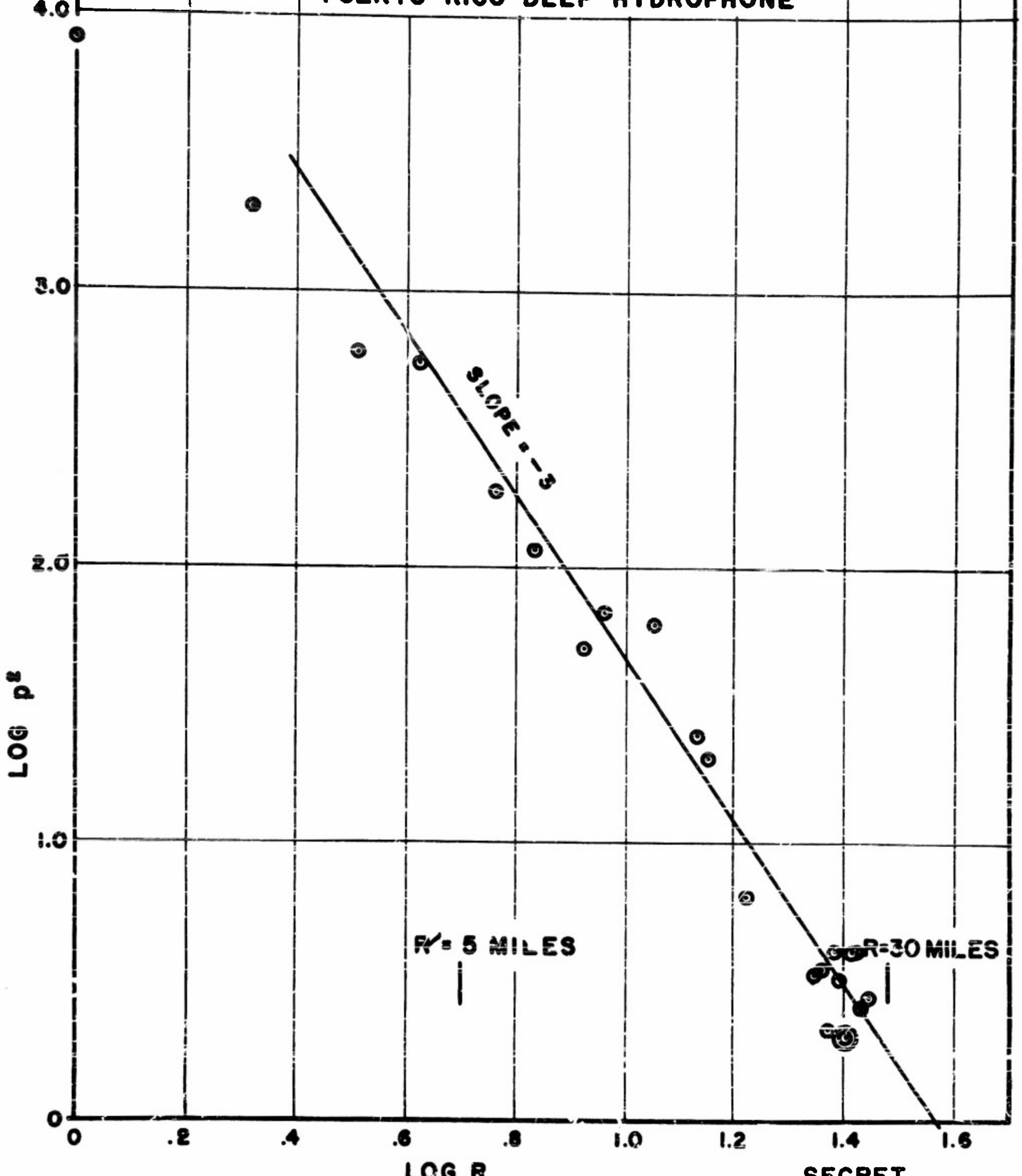

PUERTO RICO-EVENT AMOS (BEARING 007°)
ELEUTHERA-EVENT QUEEN (BEARING 047°)
(20-40 CPS)
(PRESSURE LEVEL + 10 LOG R) VS RANGE
RANGE IN MILES
10 LOG R + 10 LOG $\left(\int_0^t p^2 dt\right)$ DB ABOVE 1 DYNE/CM²
0
10
20
30
40
50
60
70
80
90
100
24
28
32
36
40
44
48

FIG. 7

LOG p^2 vs LOG R

30 CPS SOURCE

PUERTO RICO DEEP HYDROPHONE



12 ST 9-53

SECRET

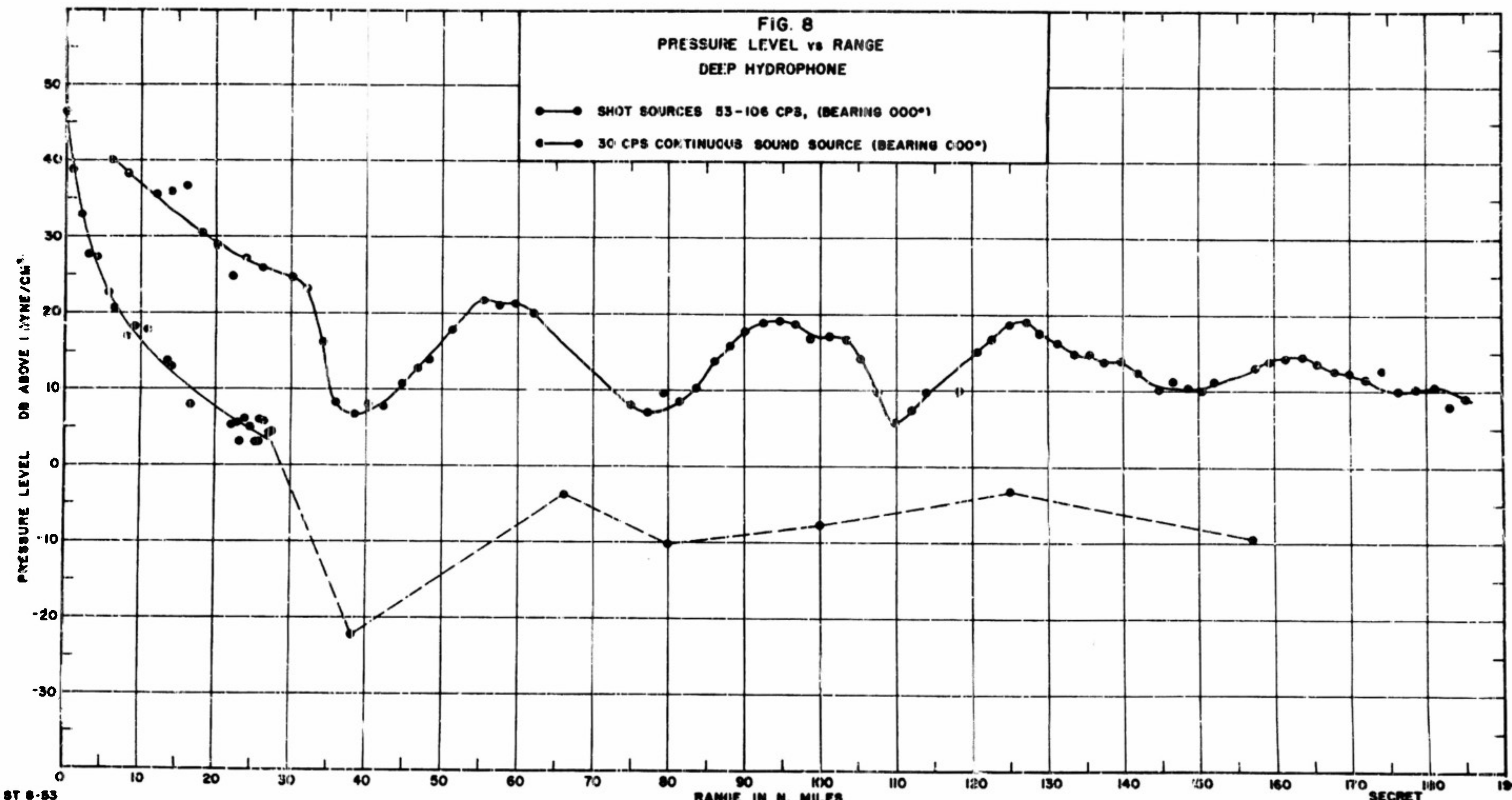


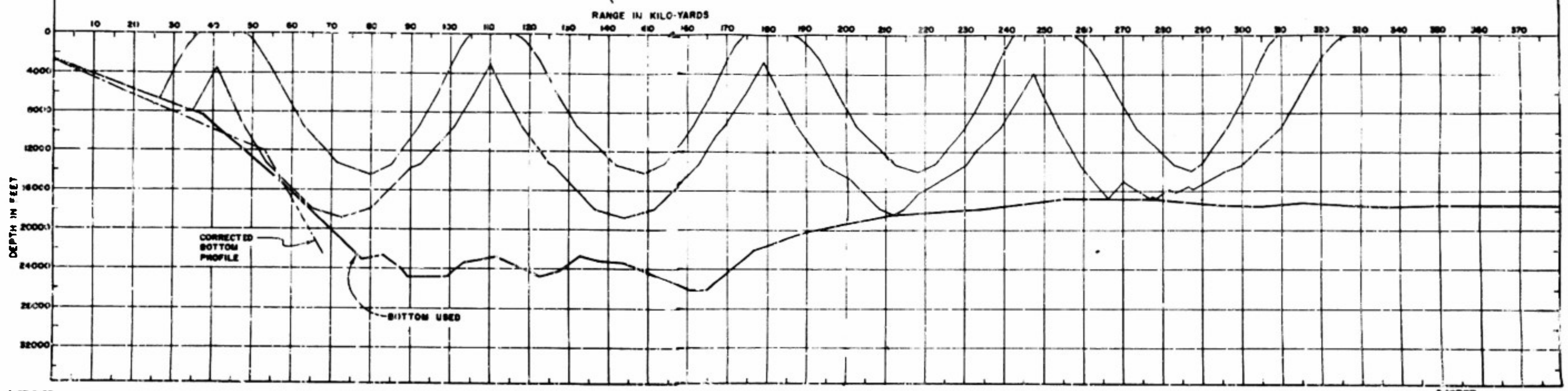
FIG. 8
PRESSURE LEVEL vs RANGE
DEEP HYDROPHONE

6 ST 8-53

SECRET
SECURITY INFORMATION

SECRET

FIG. 9
RAY DIAGRAM
PUERTO RICO DEEP HYDROPHONE



8 ST 8-83

SECRET
SECURITY INFORMATION

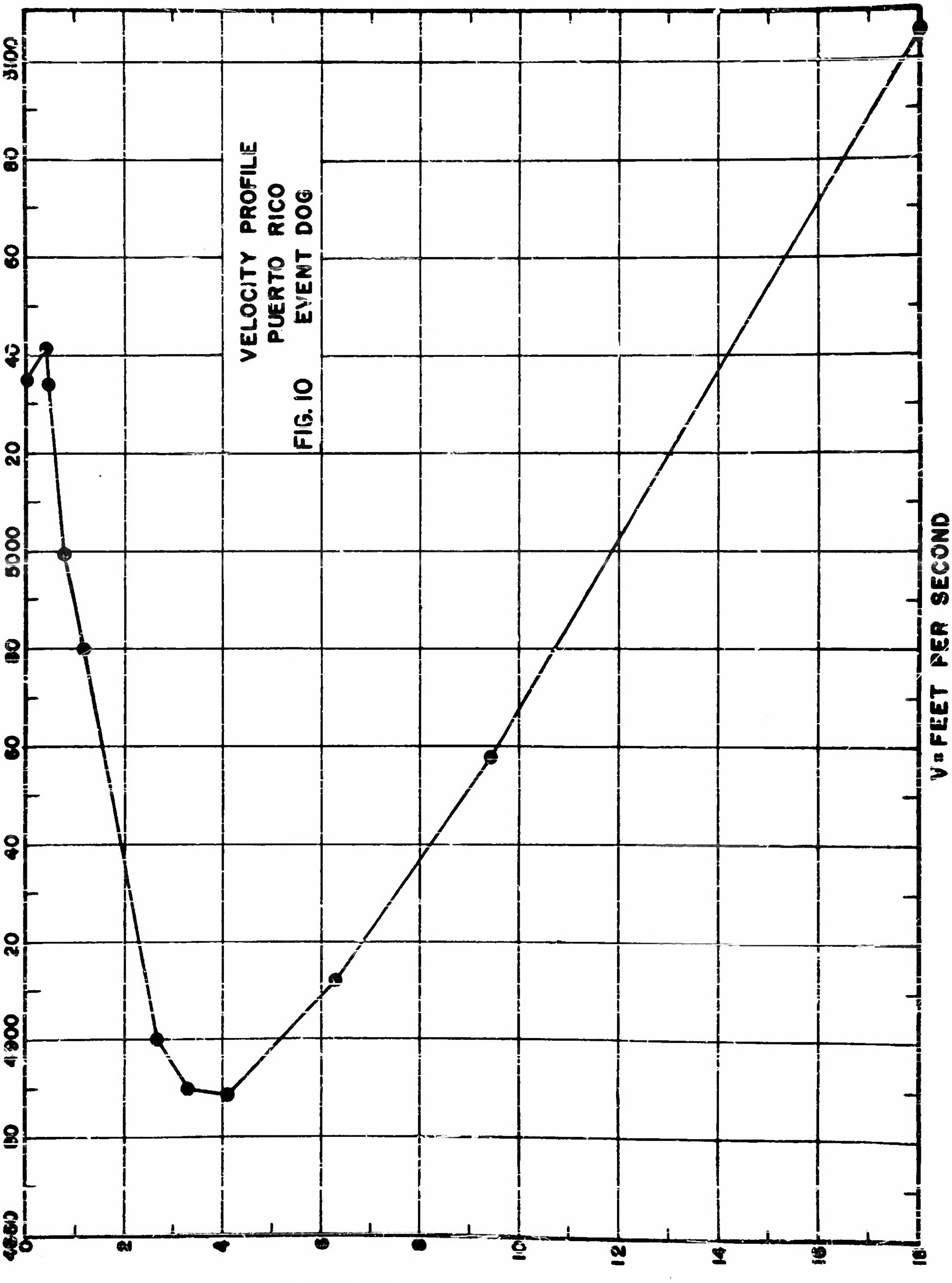
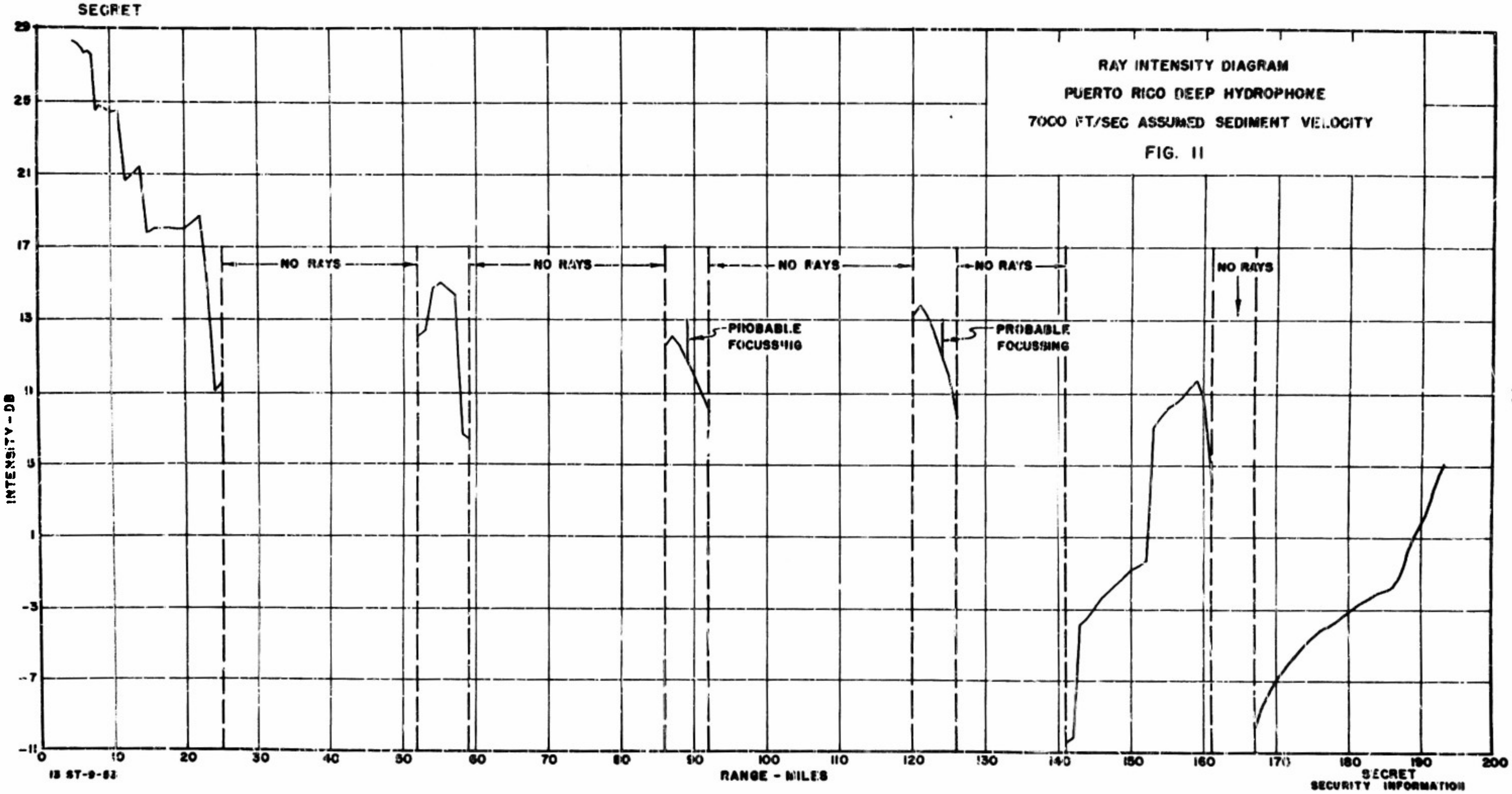

VELOCITY PROFILE
PUERTO RICO
EVENT DOG
V = FEET PER SECOND
DEPTH IN THOUSANDS OF FEET
5100
80
60
40
20
5000
80
60
40
20
4900
80
0
2
4
6
8
10
12
14
16
18

FIG. 10

SECRET



RAY INTENSITY DIAGRAM
PUERTO RICO DEEP HYDROPHONE
7000 FT/SEC ASSUMED SEDIMENT VELOCITY
FIG. 11

SECRET
SECURITY INFORMATION

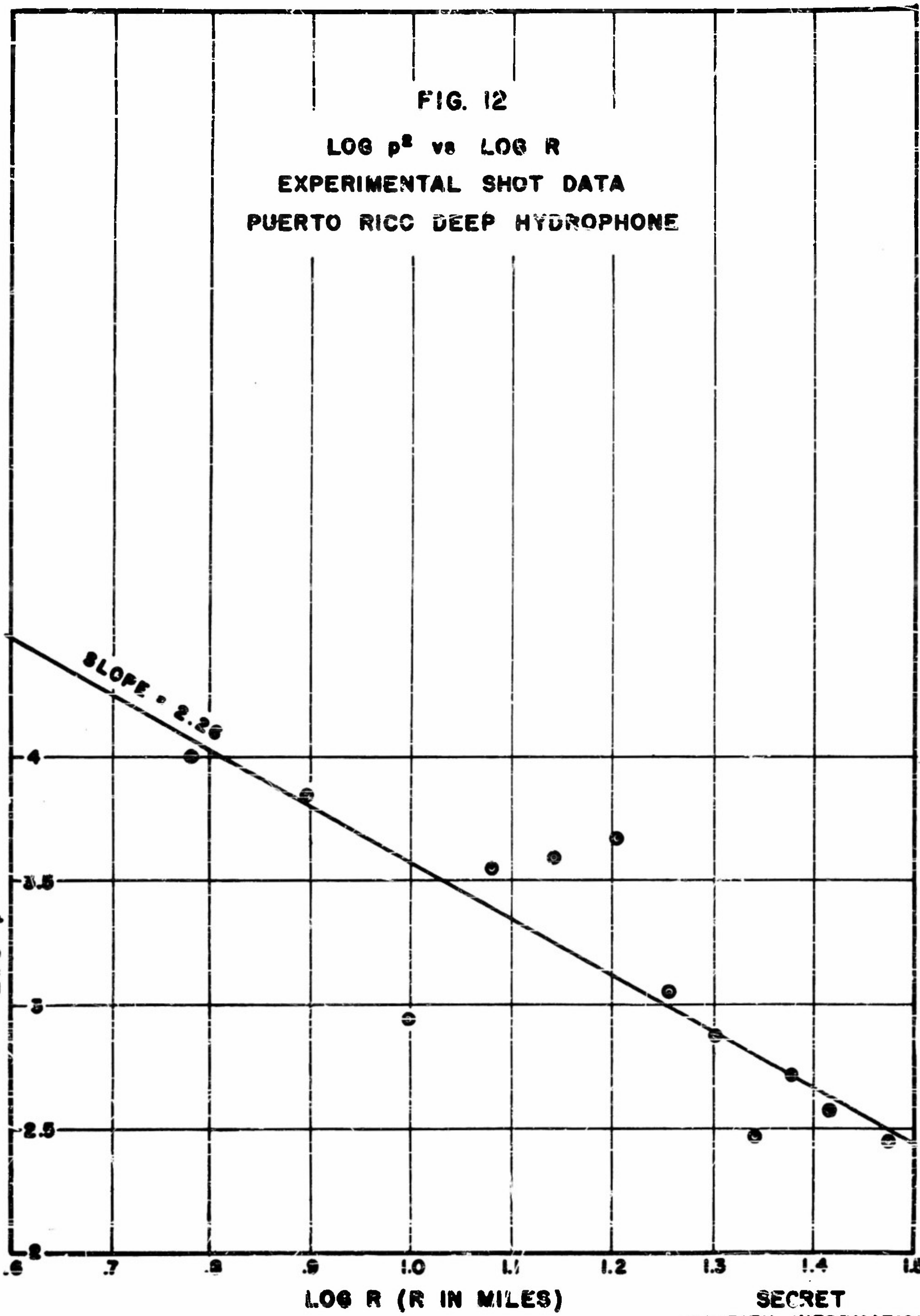
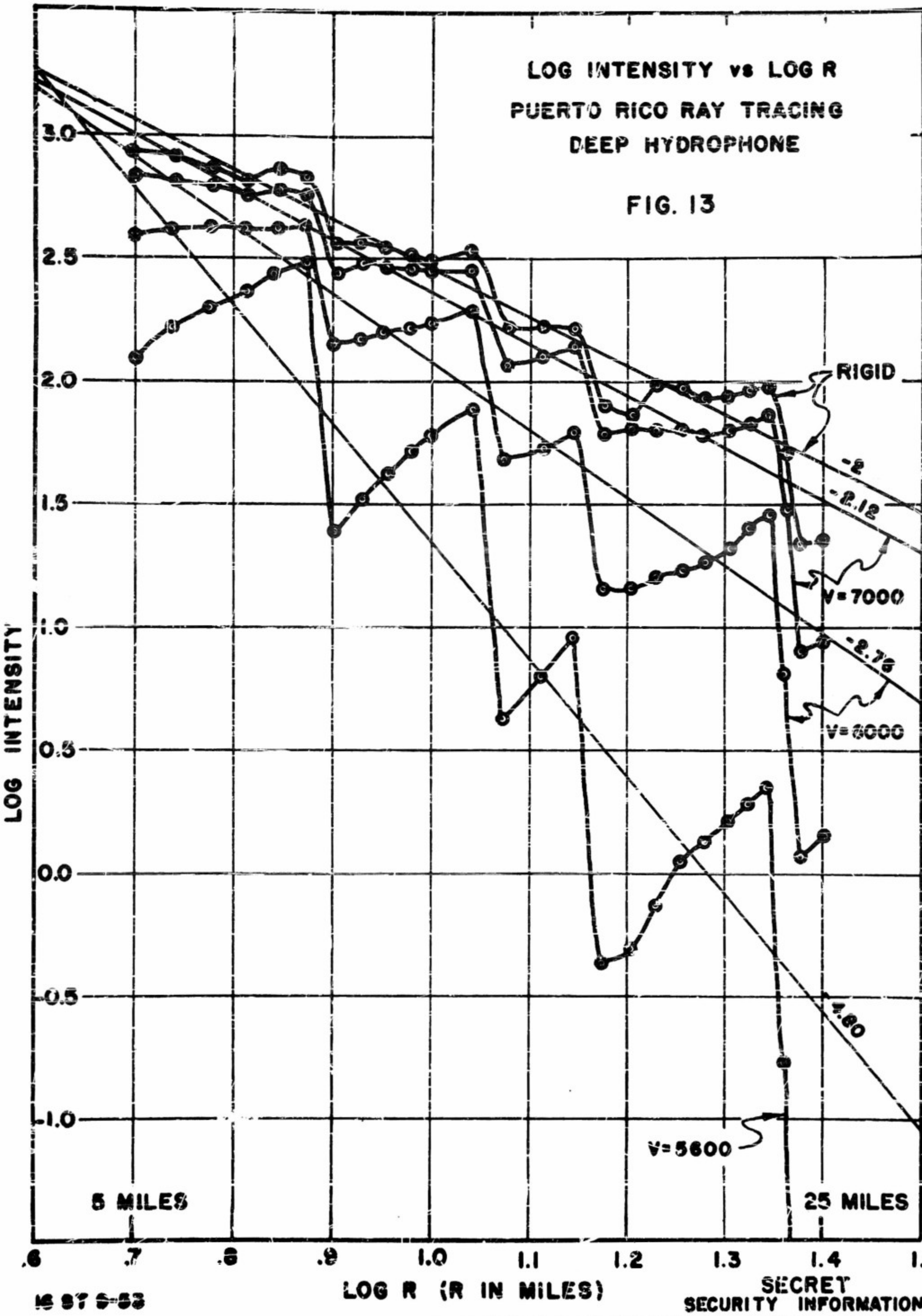


FIG. 12
LOG p^2 vs LOG R
EXPERIMENTAL SHOT DATA
PUERTO RICO DEEP HYDROPHONE
SLOPE = 2.26
4
3.5
3
2.5
2
LOG p^2
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
LOG R (R IN MILES)


LOG INTENSITY vs LOG R
PUERTO RICO RAY TRACING
DEEP HYDROPHONE
FIG. 13
RIGID
-2
-2.12
V=7000
-2.76
V=6000
-4.60
V=5600
5 MILES
25 MILES
LOG INTENSITY
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
LOG R (R IN MILES)

16 97 9-53

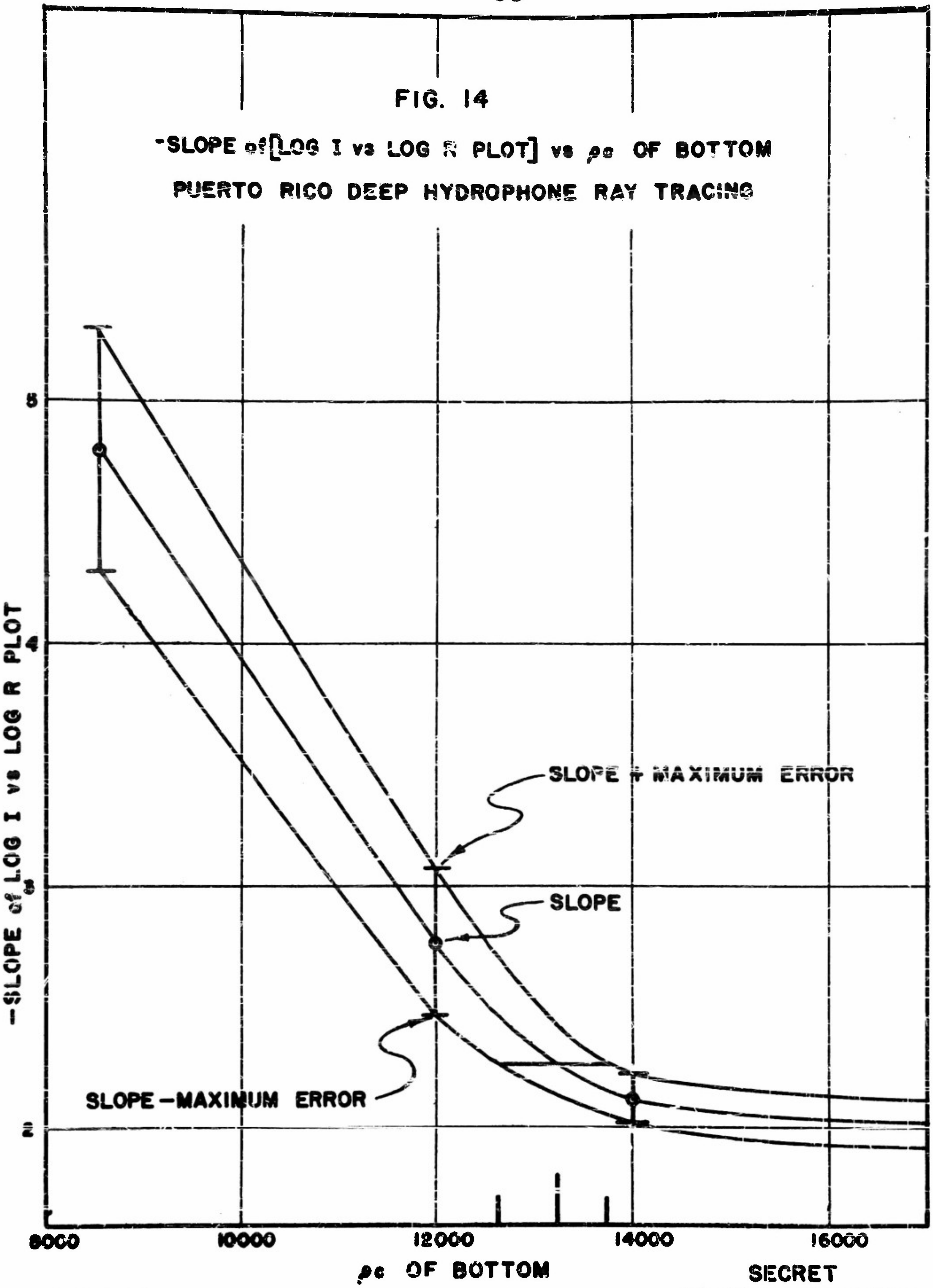
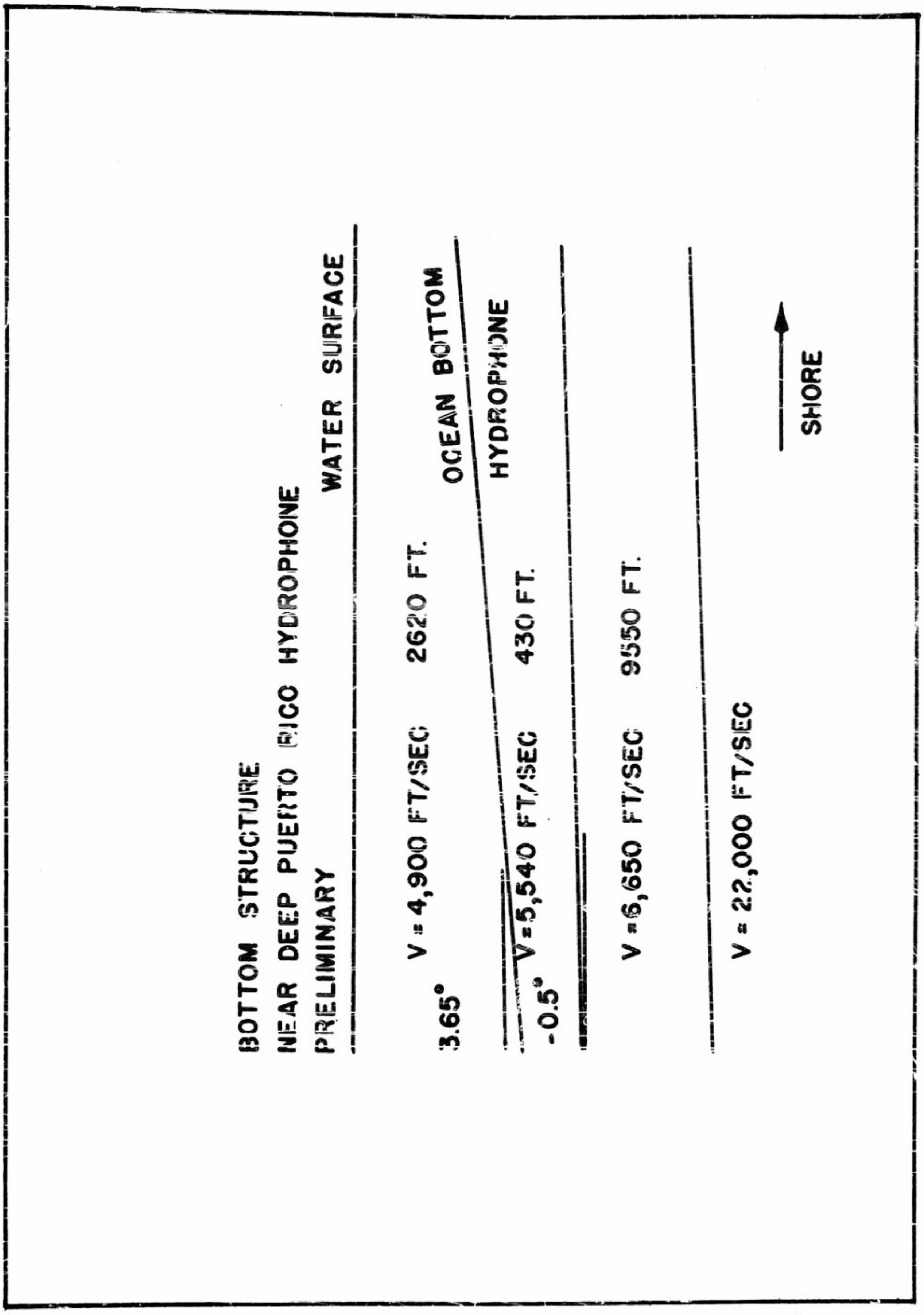


FIG. 14
-SLOPE of [LOG I vs LOG R PLOT] vs ρc OF BOTTOM
PUERTO RICO DEEP HYDROPHONE RAY TRACING
SLOPE + MAXIMUM ERROR
SLOPE
SLOPE-MAXIMUM ERROR
-SLOPE of LOG I vs LOG R PLOT
5
4
3
2
8000
10000
12000
14000
16000
ρc OF BOTTOM

15 ST 9-53



17 ST 9-53

FIG. 15